Measuring and simulating EMI on very small components at high frequencies

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***Abstract*— A new test method has been implemented for testing the EMC performance of small components like small connectors and IC's, mainly used in mobile applications. The test method is based on the EMC-stripline method. Both emission and immunity can be tested up to 6GHz, based on good RF matching conditions and with high field strengths.**

***Keywords*— EMC, EMI-stripline, small components, TEM-cell**

I. Introduction

This paper describes an extended use of the stripline method, a widely used method in the automotive industry to measure the EMC performance of cable assemblies with low frequencies (lower than 1 GHz) and relatively high field strengths. This method is extended for the telecommunications industry. The goal was to down-size the stripline so that it is usable on small telecom components and therefore can be used at much higher frequencies (up to 6 GHz) and produces much higher field strengths. These small components are very often used in mobile applications where high EMC standards have to be maintained due to the high density of the components.

Both the emission and the immunity of the component can be characterized, hence applicable for both active and passive devices.

A boundary in the setup is the height of the stripline above the board. The higher the stripline, the lower the bandwidth. The lower the stripline, the smaller the components that can be tested. A good combination of both should be found in creating enough space to put the components underneath the stripline, without losing too much bandwidth. To control the impedance adjustments, the test environment was simulated in a full wave simulator, thus allowing to adjust each design to those impedance adjustments and simultaneously creating a software environment to emulate the field strengths.

Finding a correlation between the results by software simulation and the hardware measurements, rules out the time-consuming hardware measurements and promotes the software simulation. By such it is possible to characterize the EMC behavior of small components which can be performed in any lab environment. The biggest advantage however is no redundant hardware costs, before the design is optimized. All these advantages will result in a low and cost-effective method to create small components applicable for the mobile applications, such as mobile phones, laptops, etc. This paper will describe the software simulation and the hardware setup and compare both approaches, keeping in mind the influencing factors on the dimensions, performance and correlation. Moreover, the stripline method will be compared to the well-known and widely used TEM (Transverse Electro-Magnetic) cell method.

II. Stripline Method

The stripline method is based on the concept of PCB design, namely the microstrip (Figure 1).

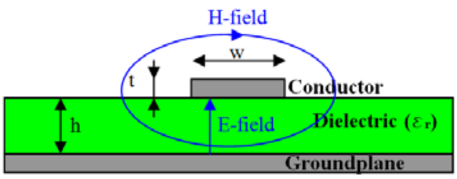


Fig. 1 : PCB design concept of microstrip

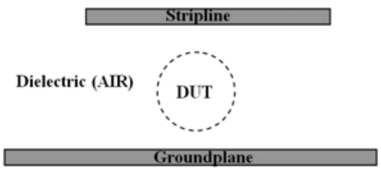


Fig. 2 : Stripline method based on PCB design concept of microstrip

The structure of the microstrip is to be designed to have a specific impedance, most commonly 50 Ohm. This impedance is defined by the width (w) and the thickness (t) of the active conductor, the distance between the active conductor and the ground (h) and the type of plastic (ε_r) used in the PCB (e.g. FR4).

Hence the impedance (Z) can be seen as defined by mechanical characteristics. Nevertheless, the correct definition of impedance is given by the field pattern, namely by the interaction of the electric field (E-field, Figure 4) and the magnetic field (H-field).

$$Z = \frac{E}{H} \tag{1}$$

The electromagnetic field, composed of the electric and the magnetic field, can be of use for EMI testing. This field is to a large extent captured in the plastic material of the PCB. This principle of the microstrip which creates an electromagnetic field can be used for radiation or immunity testing of active and passive components. It can then be extended to a test method which can define the EMI behaviour of very small components.

How to accomplish this? Keep the active conductor and the ground and replace the plastic by air. Now you are able to position a Device Under Test (DUT) between the active conductor and the ground (Figure 2). The DUT is now positioned in the EM field and it is possible to define the EMI behavior of the component.

The distance between the active conductor and the ground (in PCB-design mainly defined by the available material thicknesses) is too small (e.g. 0.2mm) to put real components in between. The EMI measurement setup should have a larger distance between these two structures, but the condition of having a 50 Ohm structure should be kept. This implies that the width of the active conductor (w) is getting bigger as the distance (h) is growing.

The larger the distance (h), the larger the range of physical measurements for the components under test, but the lower the usable bandwidth and the lower the available field strength.

So a trade off is to be made between the size of the component and the upper frequency in the application.

Moreover, another restriction is that the distance may not be too small, because in that case the active conductor gets too close to the component under test which results in a highly disturbed field. This can generate faulty results.

The solution is reached by keeping in mind that the height of the component is known, so the width must be adapted to always keep the 50 Ohm structure.

The impedance for a stripline defined by one dielectric material is calculated by the formula described in [3].

When adding a DUT between the active conductor and the ground however, the impedance of the stripline is changed (by coupling with the DUT). The nearest match to the 50 Ohm structure can be calculated by use of 3D simulation software.

An extra required feature to this setup is a tapered structure on the active conductor (septum) [1]-[3], used because of impedance matching. The shape of this tapered structure has to be calculated by use of 3D software (Figure 3).

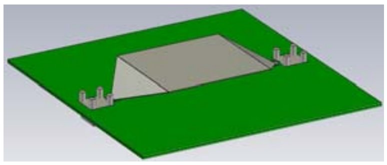


Fig. 3 : Stripline with tapered structure mounted on PCB

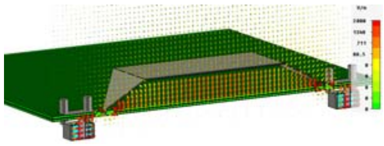


Fig. 4 : E-field between stripline and ground

III. STRIPLINE METHOD APPLIED ON MICROSTRIP STRUCTURES

A. *Defining The Setup*

The stripline method will be used for the EMI quantification of an unknown object (e.g. a connector). Since there are no references for an unknown object, a first analysis of the stripline method was performed on a simple, known structure i.e. a microstrip. This means that the DUT in Figure 2 will be replaced by a similar structure given by Figure 1, resulting in Figure 6.

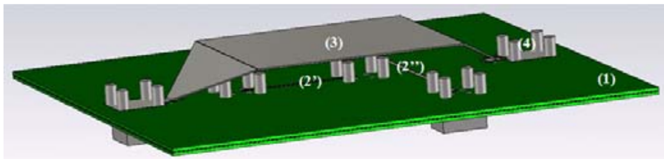


Fig. 5 : Tapered stripline mounted above microstrips on PCB

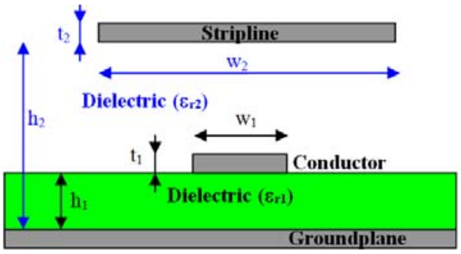
The setup in Figure 5 consists of a four-layer PCB (1) with a ground on layer 2. On the top layer of the PCB two microstrip structures (2' and 2'') have been routed which form a 50 Ohm structure with that ground. The microstrips are then considered to be the unknown radiators (DUT).

Simultaneously, the tapered stripline (3) is mounted on the PCB - above the microstrips - which will act as the receiver of the radiated energy. By measuring this energy and simulating this setup, the radiation amount of the microstrips can be determined.

SMA connectors (4) are used to feed the energy into the microstrips and to capture the energy radiated onto the stripline.

B. *Determination Of Stripline Dimensions*

The dimensions of the stripline have to be defined to create a 50 Ohm structure. The cross-section of the simulation setup is shown in Figure 6.



Settings used for calculating the stripline dimensions :

Microstrip	Stripline :
$w_1 = 0.67$mm	w_2 = To be found
$h_1 = 0.36$mm	h_2 = from 1mm to 10mm
$t_1 = 0.035$mm	$t_2 = 0.2$mm
$\varepsilon_{r1} = 4.2$	$\varepsilon_{r2} = 1$

Fig. 6 : Cross-section of simulation setup

The calculation of the width (w2) of the stripline has been performed by use of Microwave Studio [2]. A graphical overview of the width (w2) versus the height (h2) of the stripline is given in Figure 7.

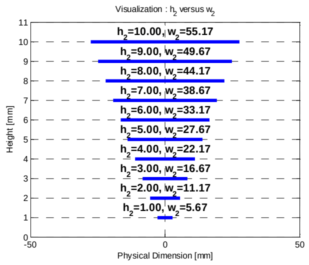


Fig. 7 : Septum - Height above ground versus width

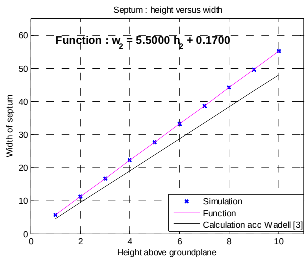


Fig. 8 : h-w Transfer function to obtain 50 Ohm

The relation between this height (h2) and width (w2) of the space between the stripline and the ground for mixed dielectric materials is given by

$$w2=5.50\,h2 + 0.17 \qquad (2)$$

The field between a microstrip and its ground is displayed in Figure 9. The biggest coupling to the ground is located in the center of the structure. The difference between formula (2) and the formula described in [5] is given by the use of two different dielectric materials and by the presence of an additional structure underneath the stripline, displayed in Figure 10. The microstrip is changing the field lines between the stripline and the ground, hence the coupling is changed and the impedance is changed.

This behavior is very valuable in understanding the case of measuring larger objects then the microstrip object. By inserting your object underneath the stripline, the field pattern will be disturbed and the impedance of the stripline will change. But, this effect can be evaluated by use of simulation software.

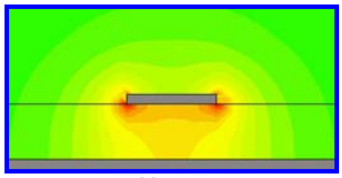


Figure 9 : H-Field pattern in microstrip

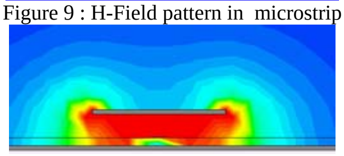


Figure 10 : H-Field pattern of stripline with microstrip as test object

C. *Validation Of The Setup By Use Of Measurement And Simulation*

The simulation model (Figure 11) has been built (Figure 12) and measured.

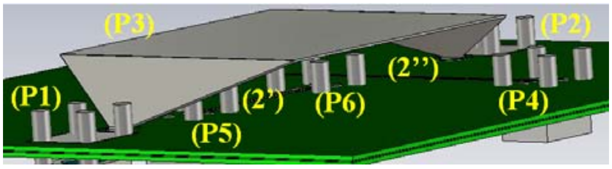


Figure 11: Simulation Model

Figure 12: Hardware Model

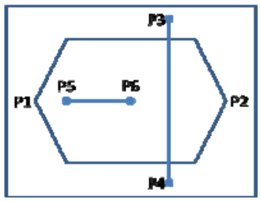


Figure 13: Connection on the Model

The first microstrip structure (2') can be used to analyze the difference between the near-end and the far-end coupling. The second microstrip structure (2'') can be used to show the physical effect of having less coupling if two traces are routed transverse instead of parallel. The near end coupling is given by feeding energy into Port 1 (P1), and receiving the energy at Port 5 (P5) of microstrip 2'. The far end coupling is monitored at Port 6 (P6). The coupling with the transverse microstrip 2'' can be measured either at Port 3 (P3) or at Port 4 (P4), thanks to the symmetry.

The coupling between the microstrip and the stripline is as shown in Figure 13 with a linear frequency axis and in Figure 14 with a logarithmic frequency axis. Measurements have been performed with a linear frequency up to 6GHz on a two port network analyzer.

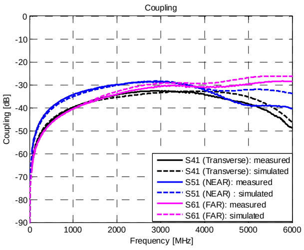


Fig. 14 : Coupling (Linear Frequency)

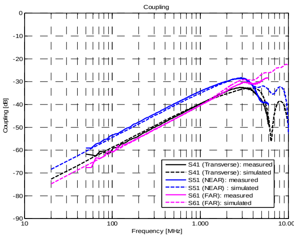


Fig. 15 : Coupling (Logarithmic Frequency)

A similar coupling characteristic has been reported in [1]-[3]. In Figure 13 the used design in this paper shows a stable performance up to 4GHz. The reported data in Figure 14 display some resonances in the transverse setup at 6.4GHz. This means that the setup can be used up to 6GHz. The near end measurement (S51) shows a 5dB better coupling than the far end measurement (S61).

The correlation between the simulation and measurement of the coupling is perfect up to 4 GHz. Some deviation arises at the higher frequencies. This can be due to small differences between the two setups.

The impedance profile has a very good match between simulation and measurement. The peaks (inductive effect) given in Figure 15 are given by the impedance mismatch in the tapered ends of the stripline. The stripline itself has been designed with a impedance of about 46 Ohm. The data is captured on a TDR device with a rise time at the test-leads of about 30ps.

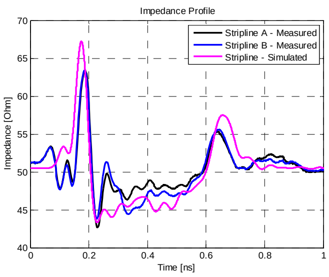


Fig. 16 : Impedance Profile

For passive structures the correlation between simulation and measurements is almost perfect. The biggest challenge will be to create representative models of active components which can reflect the EMI measurement values in a software model.

IV. STRIPLINE METHOD COMPARED TO TEM-CELL

The weakness of a lot of new EMI measurement methods is the lack of resemblance to well-known methods. The TEM-cell method is a widely spread test method and has a lot of standardization around it. This makes a comparison between the stripline method and the TEM-cell method very valuable.

The TEM-cell used for the test has an opening on top to fit PCB structures. Components mounted on a PCB can be measured in this cell, while excluding the other side of the PCB. The test PCB has been designed in such a way that it does fit in the TEM-cell. The PCB, without the striplines, has been mounted onto the TEM-cell as pictured in figure 17.

Fig. 17: TEM-cell – Top loading with DUT

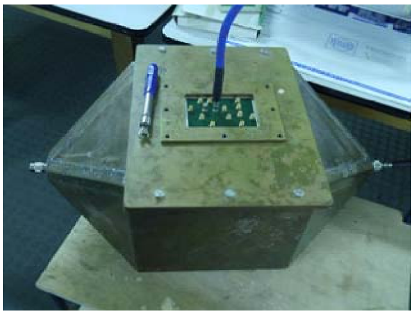


Fig. 18: Measuring with TEM-cell

The measurements have been performed with a two port Network Analyzer on the setup as shown in Figure 18. Parameter S21 is representing the coupling. The measured values from the TEM-cell set-up are compared with the stripline measurement data in figure 19.

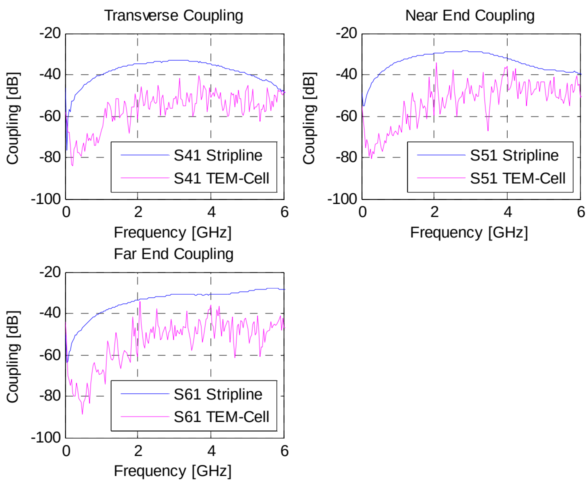


Fig. 19 : Comparison Stripline and TEM cell coupling

The difference in the results generated by the stripline method and the results generated by the TEM cell are due to a difference in measurement setup and not by a difference in the preparation of the DUT. As such, the advantage of the stripline method can be found in a much better coupling between the DUT and the test setup. This will ease the measurements as an external amplifier will not always be needed.

V. STRIPLINE METHOD APPLIED ON FUNCTIONAL LINK

Next step in the application of the stripline method is to define the EMI behavior of a functional link. In some cases, the stripline method can be chosen because of the small size of the components and because of the ability to measure both emission and immunity with the same setup. As an example, the functional link is built by a connector with integrated optical transmitter (Tx) at one side, and an integrated optical receiver (Rx) at the other side (Figure 16 and Figure 17).

Both transmitter and receiver will be positioned underneath their own stripline. The radiation and immunity of both components can be defined separately, but they will still work as one link.

As both components are active components, the main radiation direction is unknown. Hence, both a vertical positioning and a horizontal position have been foreseen on the test board.

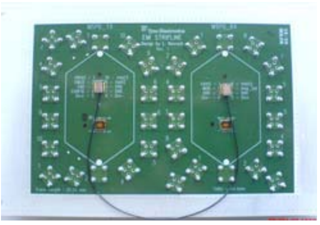


Fig. 20 : Test PCB – With DUT

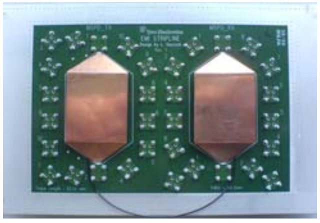


Fig. 21 : Test PCB – With Strip Line

This case shows a practical example of how to implement the stripline test technique on components.

VI. CONCLUSIONS

The stripline method is small-scaled and can therefore be achieved in a small lab, as opposed to the generally used EMC measurements which usually require large EMC measurement room. This is a first advantage of the stripline method.

The generally used EMC measurements also have the disadvantage that they can only generate low field strengths and hence low sensitivity which is not usable in this case study.

Furthermore, the stripline method can cover both emission and immunity measurements in a single measurement setup.

The most important advantage however is that this method is a 100% reproducible by computer simulations, based on passive components. This advantage can save the cost of producing prototypes and can speed up the design cycle.

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